

Development of Honda Smart Home System

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ABSTRACT

The Honda Smart Home System was developed with the aim of reducing CO₂ emissions from household living down to one-half the 2000 level. The Honda Smart Home System conducts integrated energy management of heat and electricity by using a solar power generation panel and a gas cogeneration system as an energy creation mechanism and using the battery of a next-generation electric vehicle for energy storage.

The Honda Smart Home System uses vehicle battery information and navigation data from Honda's proprietary Internavi communication system. A cloud server assembles the Internavi information with household heat and electric power information to calculate household demand prediction. The Smart e Mix Manager functions according to operation planning based on the demand prediction results, and it was configured to allow highly efficient operation in modes that give priority to either CO₂ emissions reduction or utility cost reduction. This method is expected to yield a reduction of CO₂ emissions from a household using a car by one-half relative to the year 2000.

1. Introduction

As the world economy advances, total emissions of greenhouse gases are continually increasing, and energy problems and climate change are occurring on a global scale. According to the latest statistical data from Japan's National Institute for Environmental Studies, total fiscal year 2011 emissions of CO₂, which account for 90% or more of greenhouse gases in Japan, increased 8.4% relative to 1990 (the Kyoto Protocol reference year). The household sector accounted for 15.2% of that (an increase of 48.1%) and the transportation sector accounted for 18.6% (an increase of 5.9%)⁽¹⁾. At the 19th Conference of the Parties to the United Nations Framework Convention on Climate Change (COP19) held in November 2013, the Japanese government announced its policy for 2020 of making a 3.8% reduction relative to 2005. (This will be submitted to the United Nations by the end of March 2015.) In order to achieve the stated objective, the reduction of CO₂ emissions in the household and transportation sectors will be a key issue.

The housing industry has declared that it would make the net zero energy house the standard for newly built housing by 2020⁽²⁾. Net zero means that increased energy conservation performance, renewable energy utilization, and other such enhancement of the framework and

facilities of a house reduce its net annual primary energy consumption to zero or practically zero. Meanwhile, the shutdown of nuclear power plants due to the Great East Japan Earthquake of 2011 was followed by further growing uncertainties over power supply that have led to heightened calls for safety and security in housing. Corporations are working on smart house technology to meet these demands, and widespread adoption of the technologies has recently begun.

In 2012, Honda began selling a household cogeneration unit⁽³⁾ capable of operating independently during power outages. This unit is a component element of Eco Will Plus, which achieves a balance between optimization of the heat energy generated in households and a sense of security during power outages (Eco Will Plus is a registered trade mark of Osaka Gas Co., Ltd.). Honda is also selling electric vehicles (EV), hybrid electric vehicles (HEV), plug-in hybrid electric vehicles (PHEV), and other such next-generation electric vehicles equipped with batteries. Honda has built a system that combines these products with photovoltaic (PV) panels that use natural energy. That is the Honda Smart Home System (HSHS), which is endowed with safety and convenience, and which has the aim of reducing CO₂ emission from domestic life in households that use automobiles to one-half the 2000 level. This is to report on Honda's development of this system.

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2. Development Goals

The purpose in developing HSHS was to build an energy management system for the household that includes mobility, the conceptual sense of “Realizing the joy and freedom of mobility” and “a sustainable society where people can enjoy life.” Figure 1 shows a breakdown of household CO₂ emissions in fiscal year 2011⁽⁴⁾. Achieving a one-half reduction in CO₂ calls for cuts not just in heat and electricity, but also in mobility and all other elements, as well.

The present development proposes an efficient fusion of the house with the electric vehicle and the energy creation and storage mechanism, with the following two points as the goals.

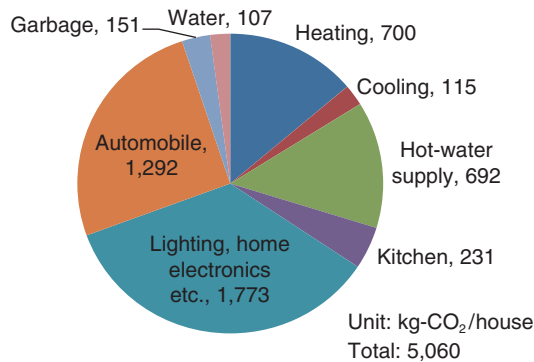


Fig. 1 CO₂ emissions from households (fiscal 2011)

- (1) Build an integrated power conditioner that links the electric vehicle and energy machines with the house. Build technology to enable the application of an EV battery as an energy storage machine without forfeiting the function of mobility.
- (2) Establish the technology to perform household demand prediction using Internavi information and household demand for electric power and heat. Determine operation plans for the energy machines based on that prediction, building a system that achieves a one-half reduction in CO₂ by producing the needed energy in the home (home production and home consumption of energy).

3. System Overview of the HSHS

Figure 2 shows the system configuration of HSHS. The energy creation and storage mechanisms, Smart e Mix Manager (SeMM), and cloud server that make up the HSHS, perform the following roles, respectively.

- (1) Micro combined heat and power system (MCHP)

The system creates electricity using a gas engine generator, recovers the waste heat from the engine, and has the capability to store the heat in a hot water heater tank. It enables household use of 1 kW of electric power output and 2.5 kW of heat output with combined efficiency of 92%. It serves as an energy creation machine that effectively generates heat and electricity in the household sector, where the level of CO₂ emissions from heating is high.

- (2) Photovoltaic (PV) panel

This serves as an energy creation machine that generates

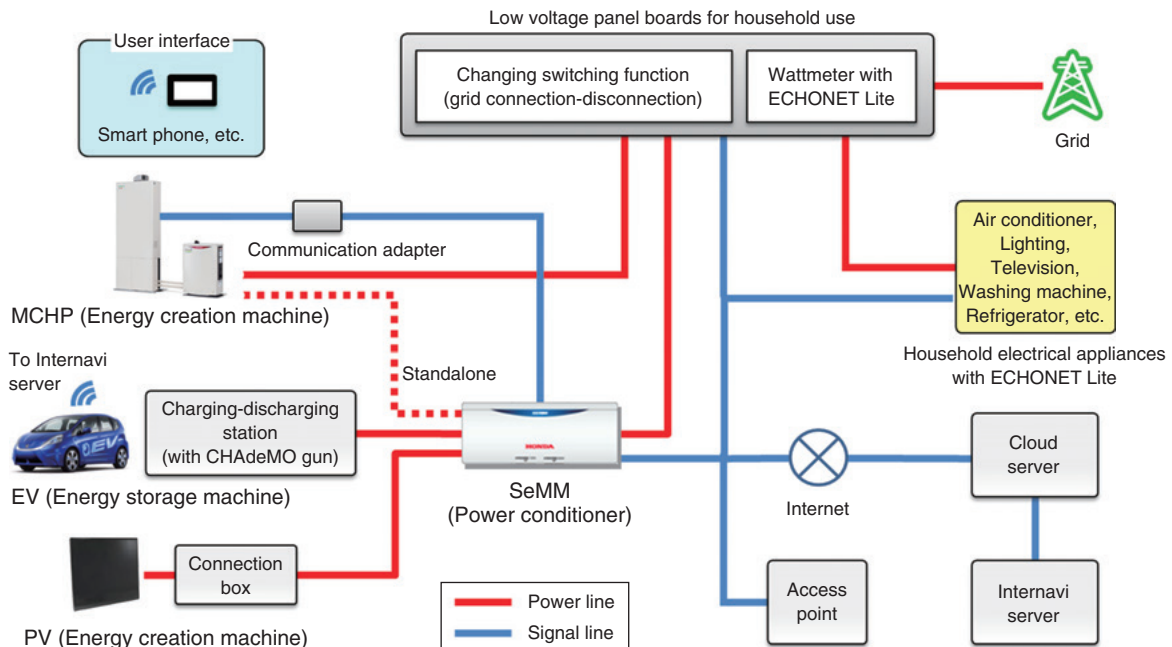


Fig. 2 System configuration of HSHS

electricity from solar energy, which is a natural energy. Its CO₂ reduction effect is large because the source of its energy is natural. The electricity can also be sold, making the system economically advantageous.

(3) Electric vehicle (EV)

In addition to its use for mobility, the utilization of SeMM when an EV is at home enables effective additional use as an energy charging or discharging and storage mechanism for electricity. The surplus power from the MCHP can be stored during midnight power service or when there is a low power load in the house, and stable power can also be supplied in the house when there is a shortfall in household or grid electric power, or when there are power outages. Since the vehicle is at home at irregular times, its application as an energy charging or discharging and storage mechanism calls for accurate prediction of periods at home together with vehicle battery information.

(4) SeMM

Providing integrated control of heat and electricity, SeMM implements the best mix of energy to maximize the separate features of the above three energy creation and storage machines when they are used in combination. SeMM controls grid interconnection, power generation, charging and discharging, and power sale in order to perform household energy management. Operation plans for the machines control the MCHP operating times and the amount of EV power charging and discharging by means of operation plans calculated on the cloud server.

When power outages occur, the combined operation of the SeMM with low-voltage panel boards for household use coordinate the MCHP, PV panel, and EV, and these three energy creation machines thus provide electricity within the household. The SeMM constantly monitors the state of the grid, and when a power outage occurs, it automatically switches to stand-alone power generation. The SeMM activates the grid interconnection/stand-alone switch built into the low-voltage panel board for household use so that power outlets can continue in use without first unplugging and replugging. The stand-alone power is supplied as single-phase three-wire power at 100/200 V so that household appliances can be used as usual even during power outages.

(5) Cloud server

Demand prediction for household heat and electricity, prediction of the amount of PV power generation, and prediction of EV at-home times are carried out on the cloud server in order to optimize the operation of energy creation and storage machines. MCHP operating times and EV battery charging and discharging amounts are controlled according to the prediction results so as to achieve increased system efficiency. The HSHS acquires information on electric power in the household from the low-voltage panel board for household use, heat information from the hot water supply system, and weather and vehicle information as well as navigation information from the Internavi server. It stores all of the information on the cloud server.

The SeMM has a constant connection to the Internet, and it coordinates home appliances by means of the Energy Conservation and Homecare Network (ECHONET) Lite⁽⁵⁾ while making its operation visible through the user interface.

This paper will introduce the technology that coordinates with the EV by means of the SeMM, which is a feature of the HSHS, and the technology that increases system efficiency by means of demand prediction and optimal control.

4. Introduction to the Developed Technology

4.1. EV Coordination Technology in the HSHS

It is a distinctive feature of the HSHS that its use of the SeMM allows the EV battery to be utilized as an energy storage machine without forfeiting the mobility function. Since it serves as an alternative to stationary storage batteries, it can reduce the user's initial investment. An overview of the EV coordination system and a description of the technology for coordinating between the house and the EV by means of Internavi communication are given in the sub-sections below.

4.1.1. Overview of the SeMM system for EV coordination

Figure 3 shows a simple function block diagram of the SeMM. A DC link system was adopted so that the EV could be charged at high efficiency using clean electric power generated by the PV panel. Higher efficiency can be anticipated because this approach enables the elimination of two power converters, an inverter and a rectifier, from an AC link with a stand-alone PV system. This also offers the advantage that maximum use can be made of electric power generated by the PV panel during grid power outages. MCHP stand-alone power can be fed in so that, if a power outage occurs, the MCHP can be operated to enable EV charging even during times of day when the PV panel is not generating power. The system can store electricity as a means for mobility during emergencies.

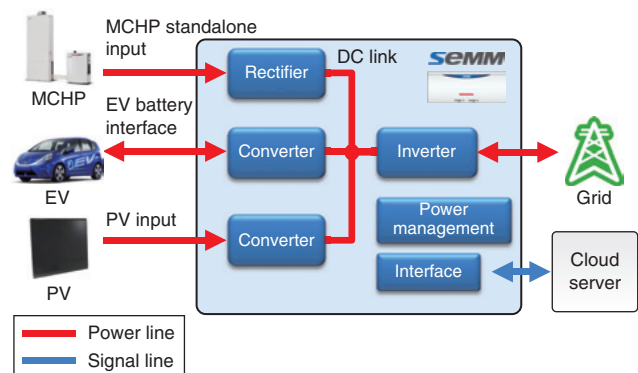


Fig. 3 Simple function block diagram of SeMM

The interface with the EV was made compliant with the DC version of the vehicle-to-home (V2H) guidelines published by the Electric Vehicle Power Supply System Association (EVPOSSA) in May 2013, as well as with CHAdeMO⁽⁶⁾, as a measure to enhance versatility and compatibility with products from other companies. When a vehicle that supports V2H is connected, the system goes to V2H mode and engages in charging or discharging operation. An isolated-type converter unit is used to connect to the EV in order to comply with Article 199, Paragraph 2⁽⁷⁾ of the Interpretation of Technical Standards for Electrical Equipment as amended in June 2012.

4.1.2. Technology for combining house-EV information using Internavi communication

Figure 4 shows a simple network configuration of SeMM. An EV battery is unlike a stationary storage battery in that it has a mobility function. This system uses remaining state of charge (SOC) information about the EV battery together with navigation information so that it can employ the EV battery as an energy creation and storage machine without obstructing that function. When the EV is linked to the house, SOC information is downloaded through communication between the SeMM and the EV, and when the EV is away, the information is downloaded from the EV by means of the Internavi server. This arrangement allows the cloud server to monitor the SOC at all times. The EV navigation information is uploaded through the Internavi server to the cloud server. The configuration was arranged so that household and EV information is centrally managed on the cloud server, where optimal energy machine operation plans are calculated.

Automatic control is the basic mode of HSHS operation. However, the system is also configured with a charge and discharge mode that the user can choose to set to give priority to the means of mobility so as not to obstruct “the joy and freedom of mobility” when the user, for example, suddenly decides to go out.

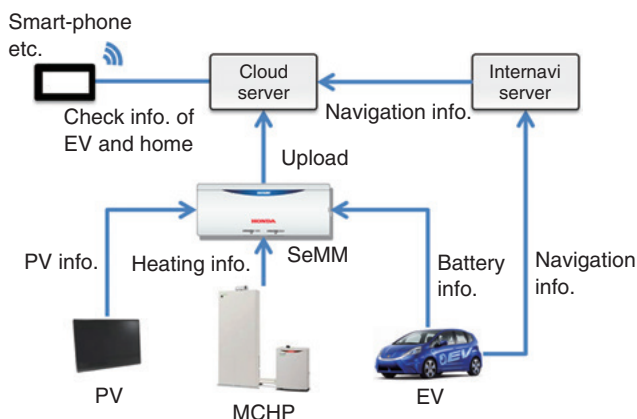


Fig. 4 Simple network configuration of SeMM

4.2. Energy Demand Prediction and Operation Planning Technology

HSHS has two strategies for reduction of CO₂ emissions. One is improvement of efficiency in each component (e.g., MCHP, PV) and the other is an optimal operation plan in each component using energy demand prediction. When the prediction is in good agreement with actual energy demand, the SeMM controls each component on the basis of the operation plan. If the prediction is not in good agreement with actual energy demand, the SeMM uses instantaneous control in consideration of the contracted electric power. Under present laws and regulations, reverse power flow to the grid is not allowed when an EV is discharging. The system is therefore provided with a reverse flow prevention function for when sharp load fluctuations occur. This system mainly consists of two parts: one is energy demand prediction and the other is the operation plan. Therefore, in the following sub-sections, an overview of the system, energy demand prediction methods and their accuracy, and operation planning based on energy demand prediction are shown.

4.2.1. System Overview

Figure 5 shows a conceptual diagram of the energy demand prediction and optimal control system. The present energy demand status of the house is sent from the SeMM over the Internet to the cloud server. On the cloud server, the future energy demand is predicted and operation plans for the components are generated. The generated operation plans function by means of the Internet and the SeMM to control the operation of each component. It is a distinctive feature of this system that it always keeps energy demand data stored in a database (DB), and by using that data to make predictions, it keeps up with changes in family structure and electric appliances in the household as it continues to yield a CO₂ reduction effect. The system detects the differences between demand predictions and actual demand, and when the difference is large, it makes a further prediction. As described above, the system continues to reduce CO₂ emissions by means of improved prediction accuracy.

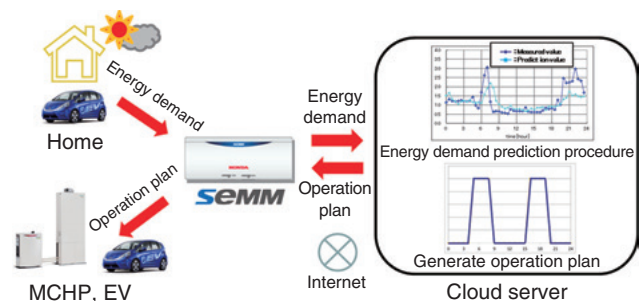


Fig. 5 Conceptual figure of prediction energy demand and operation plan

4.2.2. Energy demand prediction

Figure 6 shows a conceptual diagram of energy demand prediction. The system predicts future energy demand by an approximation model that is generated by machine learning of past energy demand. The HSHS improves prediction accuracy by a method of performing automatic categorization of energy demand and generating an approximation model⁽⁸⁾ of each domain that has been categorized.

More detailed explanations of the approximation model, categorization, and performance evaluation are described below.

(1) Approximation model

The approximation model of energy demand prediction is a function that takes past energy demand as input values and outputs future energy demand. That approximation model includes a number of parameters, the values for which are estimated by machine learning using DB. Support Vector Regression (SVR)⁽⁹⁾, which possesses a high degree of generalization performance in approximation models, is used for energy demand prediction.

(2) Categorization

Categorization of energy demand data uses the K-means method⁽¹⁰⁾. The K-means method is a form of unsupervised learning that uses an algorithm to automatically perform categorization just by inputting data.

(3) Performance evaluation

The prediction performance evaluation data consisted of 230 days' worth of actual demand data from the demonstration house⁽¹¹⁾ that Honda has been operating since April 2012. The system used data from the past 72 hours to predict the coming 48 hours. Prediction accuracy was evaluated by taking one day's worth of data from the 230 days of demand data as evaluation data, with the remainder used as learning data. Following the evaluation, the testing was repeated using the leave-one-out method so that all the days would be taken as evaluation days one time.

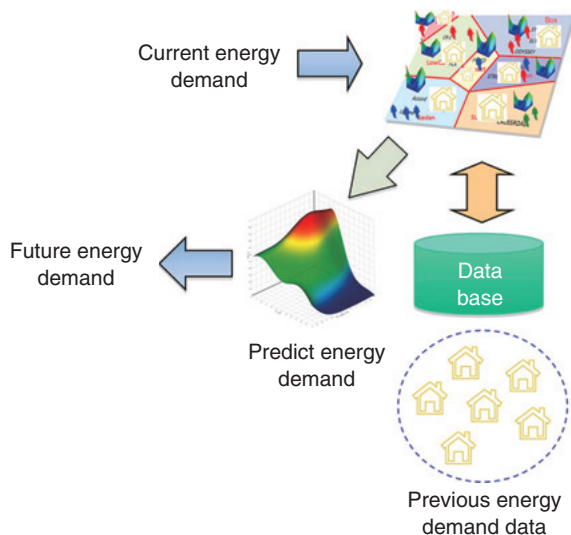


Fig. 6 Energy demand prediction procedure

Table 1 Prediction accuracy results

Item	Average 3 days	w/o clustering	w/ clustering
RMSE	0.267	0.225	0.215
Correlation	0.069	0.591	0.647

Root mean square error (RMSE) and correlation coefficient were used as the two prediction performance evaluation indices. A larger root mean square error value indicates a larger prediction error, and a correlation coefficient value that approaches one more closely indicates a stronger correlation, meaning that the model has a high degree of reproducibility. The above evaluation indices were used to evaluate prediction performance. The following two methods were used for the purpose of comparison.

- Taking the average of the preceding three-day period as the prediction data
- Prediction by the approximation model alone without categorization

Table 1 shows evaluation results. Both the root mean square error and the correlation coefficient indicate a high level of performance by the proposed method, verifying the validity of this method.

4.2.3. Operation planning technology using demand prediction

Utilizing the prediction data described above, calculations are carried out on the cloud server to minimize CO₂ emissions or to minimize fuel and lighting expenses. The MCHP operation plans and battery charging and discharging patterns are decided accordingly. The SeMM controls the energy creation and storage machines to yield benefit for the user as well as to meet the CO₂ reduction target. Figure 7 shows an example of an operation plan that includes the vehicle. The EV is in use for mobility

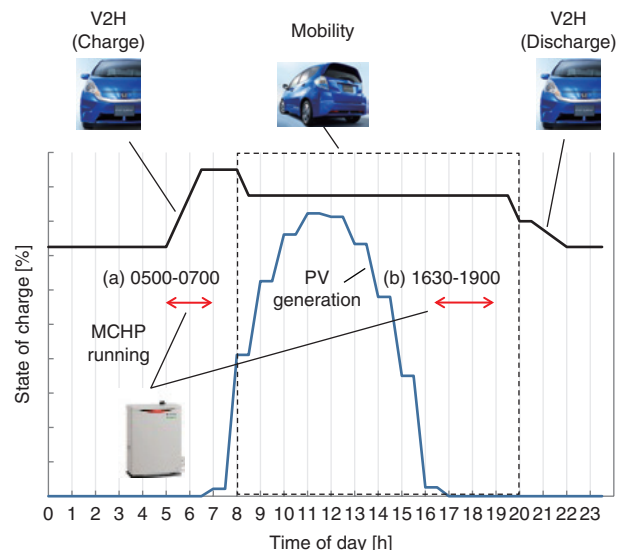


Fig. 7 Example of vehicle and MCHP operation plan

Table 2 Machine specifications for simulation

MCHP		PV panel	EV battery
Heat	Electricity		
2.5 kW	1 kW	4.6 kW	20 kW-h*

*EV battery can be used in V2H mode from 2000 to 0800 hours.

Table 3 Assumptions regarding annual demand

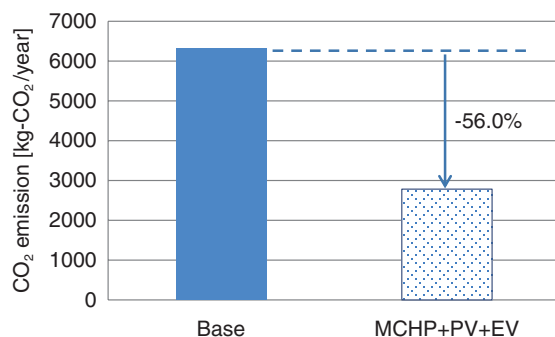
Number of people	Heat demand	Electrical demand	Mobility mileage
4	7028 kW-h	5250 kW-h	8000 km

- Calculation conditions -

Electric power consumption rate 0.69 kg-CO₂/(kW-h), Gas consumption rate 2.31 kg-CO₂/m³, Gasoline consumption rate 2.32 kg-CO₂/L, EV efficiency (JC08 mode)106 W-h/km, Fuel efficiency 16.6 km/L

away from the household from 0800 to 2000 hours. At other times the EV is at the house, and those are designated as possible V2H times. The MCHP ordinarily operates at peak demand times in the morning and evening. Charging operation is carried out to match MCHP operation (a) in the morning, thus limiting the amount of surplus power from the MCHP. During MCHP operation (b) in the evening, surplus power is unlikely to be generated because household power consumption is high, and operation is matched to heat demand even when the EV is not present. After the EV returns home, it is made to discharge at times when the household load is large during the period before midnight power service goes into effect. System efficiency can be expected to increase due to demand prediction and operation planning technology.

The annual amount of the CO₂ reduction achieved when control of the energy machines is implemented so as to minimize CO₂ emissions was calculated. Figure 8 shows the results from simulated optimization in terms of CO₂. Table 2 shows the specifications of the energy creation and storage machines used in the simulation. Table 3 shows the assumptions that apply to annual demand for electric power and heat as well as to vehicle operating distance. These tables indicate that the operation of this system and

Fig. 8 Simulation result of annual CO₂ reduction rate

the application of the control technologies described above, including mobility operation, can be anticipated to achieve an annual reduction by one-half in the base value for CO₂ emissions under conditions of gasoline-fueled vehicle use without operation of the energy creation and storage machines, confirming the usefulness of this approach.

5. Conclusion

The HSHS was developed as a total energy management system that combines mobility and energy machines (MCHP and PV panel) with the house. Realization of the main technologies yielded the following conclusions.

- (1) Coordination of the SeMM with Internavi realized utilization of the EV as an energy charging or discharging and storage mechanism that serves as an alternative to a stationary storage battery. Value-added use of the electric vehicle can thus be anticipated to reduce the user's initial investment.
- (2) Technology that calculates household demand prediction based on Internavi information and household power and heat information, and that implements optimal control for high efficiency based on the demand prediction results, was established. Future application of this technology and operation of the SeMM according to operation plans based on predictions can be anticipated to achieve a one-half reduction in CO₂ emissions relative to conventional machines.

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